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# Reduction of contrast agent dose at low kV settings

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Fig 1: Clinical example of a patient scanned both with a default 120 kV protocol with 120 ml of contrast agent on the predecessor scanner generation (left) and with a reduced kV protocol (90 kV) with only 70 ml on the SOMATOM Force. The images on the right show comparable contrast and image quality for both scans.  
 [Image courtesy of Mayo Foundation for Medical Education and Research, Rochester, MN, USA]

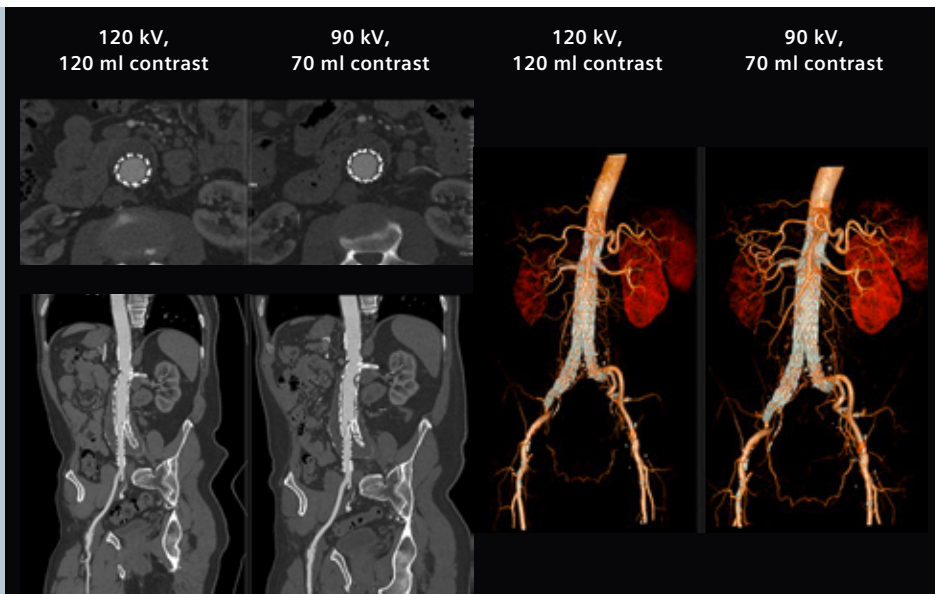


Fig. 1

## Introduction

Automated tube voltage selection enabled by Siemens CARE kV can be used for multiple clinical applications, with one of the most beneficial being contrast-enhanced scans with lower radiation dose but with consistent image quality.

This is an established method that is currently being used in clinical routine and that can help to reduce the radiation dose significantly. Overall, tube potentials between 70 and 100 kVp have been shown as most effective for clinical contrast CT examinations, depending on the specific situation.

With the advent of CT scanners with X-ray tubes powerful enough to produce high mAs at low kV (e.g. SOMATOM Force), the same physical behavior of X-rays and iodine contrast agent can be used in clinical routine to reduce the amount of contrast agent instead of radiation dose.

This white paper briefly summarizes the scientific background and explains the principle of saving contrast agent dose instead of radiation dose.

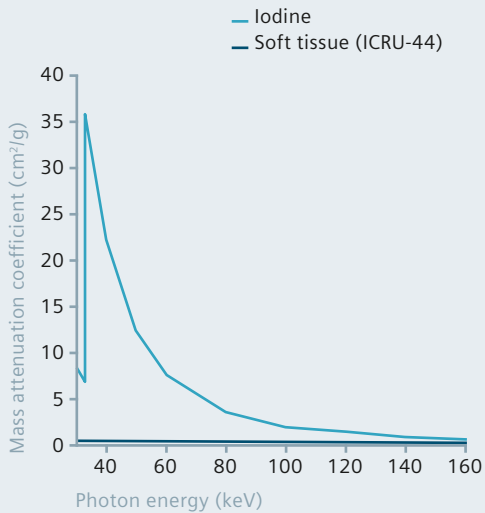


Fig. 2

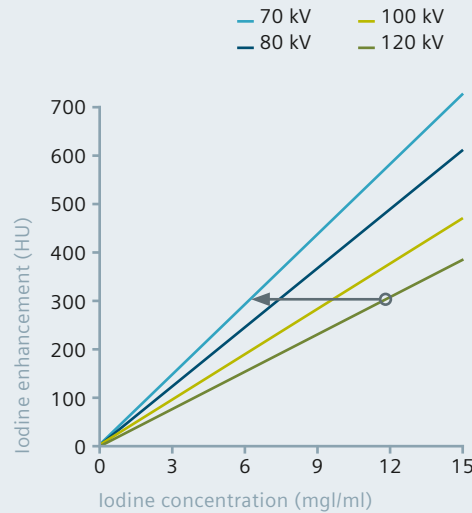


Fig. 3

Fig. 2: Mass attenuation coefficients for soft tissue and iodine at different photon energies. At lower energies, the difference in absorption between soft tissue and iodine increases, which results in a higher iodine contrast in the image. The K-edge of iodine leads to the spike visible at 33.2 keV.

[Data from NIST tables]

Fig. 3: With static iodine phantoms, the increase in iodine enhancement (in HU) at a lower kV can be verified [data from iodine samples in 20 cm water phantom]. The arrow indicates how much iodine can be saved in constant enhancement when going from 120 to 70 kV.

## Scientific background

The actual basis for low kV imaging is the mass attenuation coefficient, which is a property that depends on the chemical composition and density of a material and determines the specific absorption of X-ray beams by this material.

Fig. 2 shows that for lower photon energies, the mass attenuation coefficient of iodine increases, whereas soft tissue is less energy-dependent. This means that with low kV imaging, and thus lower average photon energy, the iodine to soft tissue contrast in the CT image (in Hounsfield units, HU) will increase. This can be easily verified by scanning a static phantom with different iodine concentration samples at different tube voltages. (Fig. 3).

Due to the linear relationship between iodine concentration and enhancement, Fig. 3 shows instantly how much iodine can be saved if the attenuation is kept constant. For example, if an iodine enhancement of 300 HU is desired, the iodine concentration at 70 kV can be ~50% lower than the iodine concentration at 120 kV.

		New/Alternative kV								
		70 kV	80 kV	90 kV	100 kV	110 kV	120 kV	130 kV	140 kV	150 kV
Reference kV	70 kV	0.0%	+18.2%	+37.2%	+57.7%	+77.0%	+96.9%	+113.7%	+135.5%	+153.8%
	80 kV	-15.4%	0.0%	+16.0%	+33.3%	+49.7%	+66.7%	+80.8%	+98.8%	+114.6%
	90 kV	-27.1%	-13.8%	0.0%	+14.9%	+29.0%	+43.7%	+56.0%	+71.5%	+85.2%
	100 kV	-36.6%	-25.0%	-13.0%	0.0%	+12.2%	+25.0%	+35.5%	+49.3%	+61.0%
	110 kV	-43.5%	-33.2%	-22.5%	-10.9%	0.0%	+11.4%	+20.8%	+33.0%	+43.5%
	120 kV	-49.2%	-40.0%	-30.4%	-19.9%	-10.2%	0.0%	+8.5%	+19.3%	+28.9%
	130 kV	-53.2%	-44.7%	-35.9%	-26.3%	-17.2%	-7.8%	0.0%	+10.0%	+18.8%
	140 kV	-57.5%	-49.7%	-41.7%	-33.0%	-24.8%	-16.2%	-9.1%	0.0%	+7.9%
	150 kV	-60.6%	-53.4%	-46.0%	-37.9%	-30.3%	-22.4%	-15.8%	-7.3%	0.0%

Fig. 4: Table displaying the relative change in iodine dose associated with lowering or increasing the tube voltage for constant iodine enhancement in 30 cm of water. [Data from phantom experiments with static iodine concentration]

Fig. 4

When comparing the relative iodine enhancement between all different kVs from 70 to 150 kV with each other, it is possible to calculate the % of iodine dose saving that may be achieved with a decrease in kV while yielding the same iodine enhancement (Fig. 4).

reference kV	→	new kV	%
120 kV	→	120 kV	0.0%
120 kV	→	110 kV	-10.2%
120 kV	→	100 kV	-19.9%
120 kV	→	90 kV	-30.4%
120 kV	→	80 kV	-40.0%
120 kV	→	70 kV	-49.2%

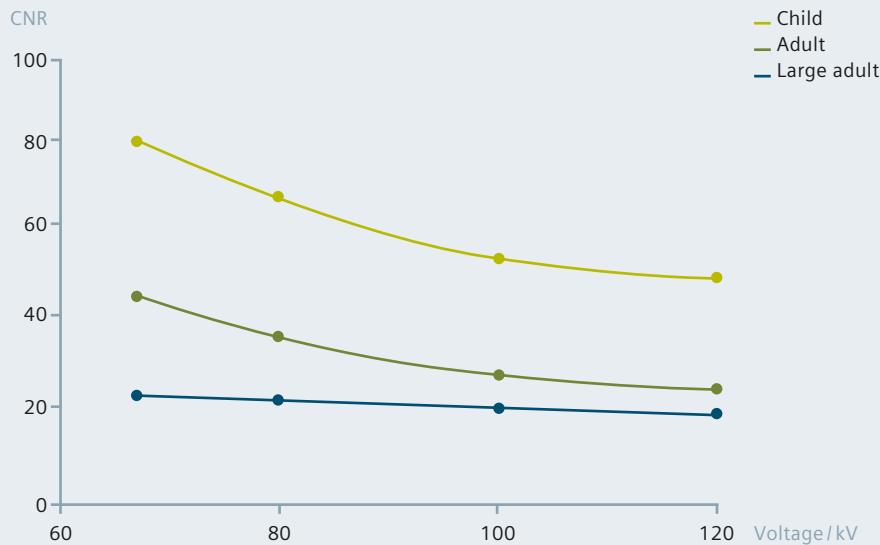


Fig. 5: CNR vs. kV (fixed CTDI<sub>vol</sub> & iodine dose)

Fig. 5: CNR increases for lower kV settings at fixed CTDI<sub>vol</sub> and fixed iodine dose. This effect and therefore the potential for iodine saving is less pronounced in large patients.

## The principle of saving contrast agent dose

The main aim of Siemens CARE kV is to maintain image quality when changing the kV, with image quality defined in terms of the contrast-to-noise ratio (CNR). Since it is directly dependent on enhancement, the CNR increases for lower kVs if radiation and iodine dose are fixed (Fig. 5). This fact can be utilized to either save radiation dose or iodine dose while keeping the CNR constant; however, it is dependent on patient size. Before explaining the principle of saving contrast agent dose, the principle of saving radiation dose will briefly be reviewed.

### Saving radiation dose

The starting point for saving radiation dose is the assumption that the same injection, protocol (amount, concentration and timing) of the reference protocol (R) would be used for all kVs, which inherently leads to an increase in iodine attenuation with decreasing kV.

As the iodine contrast increases, noise can be allowed to increase by the same extent to maintain the CNR. Then for each kV level, the respective tube current (mAs) required to reach the desired noise level is determined, as well as the corresponding radiation dose (CTDI<sub>vol</sub>). Finally, the kV level yielding the lowest radiation dose that can be achieved by the system will be chosen.

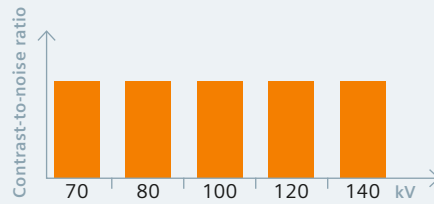
This methodology is schematically illustrated in Fig. 6a. More information can be found in the CARE kV White Paper as well as the user guide "How to scan with CARE kV".

### Saving contrast agent dose

If the aim is to reduce the contrast agent dose instead of the radiation dose, the same steps need to be performed as when saving radiation dose. However, these 4 steps should be taken in the opposite order, as described on the next page and as illustrated in Fig. 6b.

Fig. 6

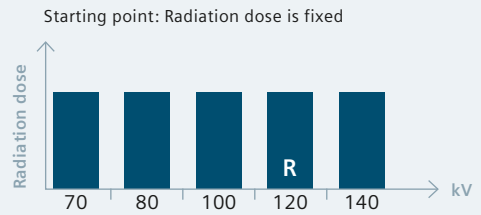
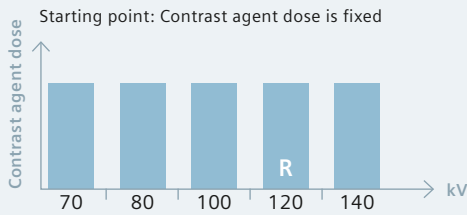
Aim: Constant image quality (CNR) for all tube voltages



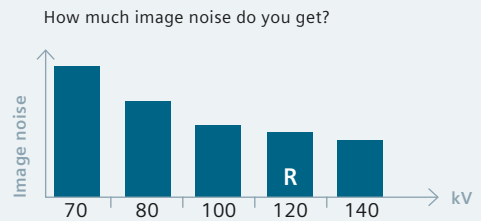
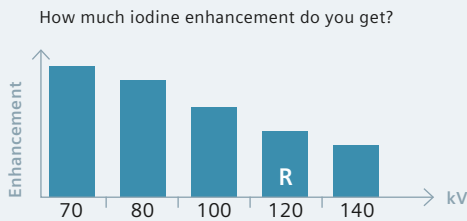
a) Save radiation dose (CARE kV)

b) Save contrast agent dose

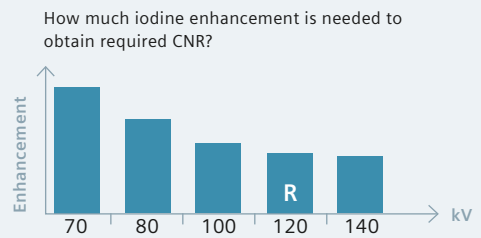
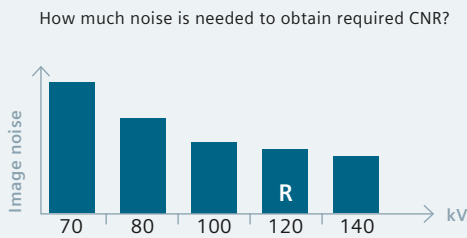
Step 1



Step 2



Step 3



Step 4

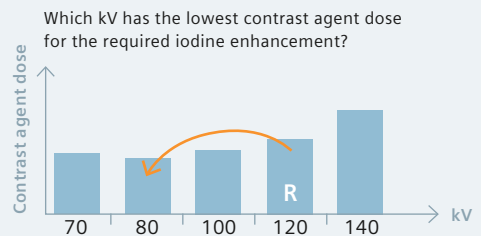
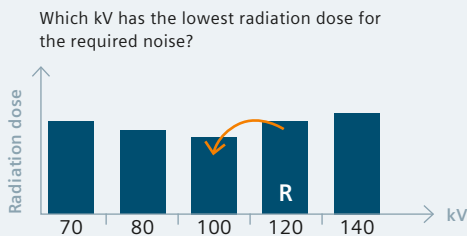


Fig. 6: Low kV imaging at constant contrast-to-noise ratio:  
 a) Principle of saving radiation  
 b) Principle of saving contrast agent dose  
 R denotes the reference protocol.

### Step 1

When reducing the contrast agent dose (Fig. 6b), the new starting point is the radiation dose ( $CTDI_{vol}$ ) of the reference protocol (R), which should be kept constant for all kV levels. This can be achieved by adjusting the tube current (mAs). Until now this step had not been possible in clinical routine due to certain technical limitations of CT systems: The X-ray tubes of existing CT systems were not powerful enough to produce sufficient tube currents at low kV settings to maintain the  $CTDI_{vol}$  of the reference protocol. Consequently, measures to save iodine dose were only feasible in pediatric or very thin patients. However, with the recent release of a new X-ray tube (Vectron tube, Siemens AG) with vastly increased tube power at low kVs ( $2 \times 120$  kW,  $2 \times 1,300$  mA at 70–90 kV, as integrated in the SOMATOM Force) it is now possible to scan even obese patients at low tube voltages with sufficiently high mAs and thus offer the possibility of contrast agent dose reduction.

### Step 2

For each kV and mAs combination, the resulting image noise can be calculated using the topogram of the patient. It is important to stress that a specific radiation dose will not result in the same image noise at the different tube voltages. Particularly at a lower kV, the image noise will be higher for a given  $CTDI_{vol}$ . Although this effect is small, it reduces the contrast agent reduction potential that would be possible if one were to consider only the increased iodine enhancement at a lower kV.

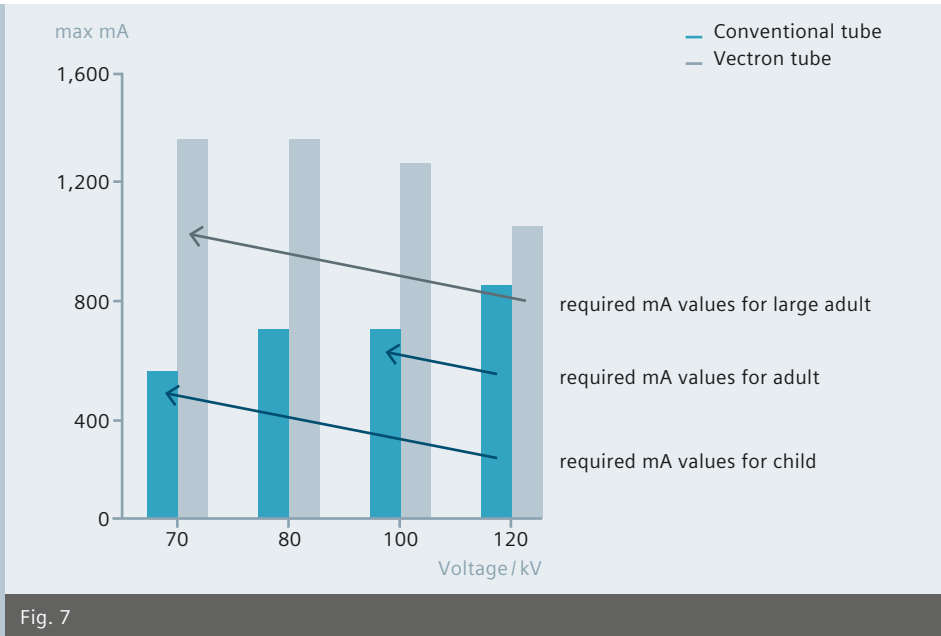
### Step 3

With the expected image noise calculated in step 2, the iodine enhancement that is required to preserve the desired CNR can be calculated for each kV.

### Step 4

If the required iodine enhancement is known, the corresponding contrast agent dose at each kV can be calculated. Based on this, the tube voltage setting that requires the lowest iodine contrast agent dose to reach this enhancement level can be selected.

Fig. 7: Maximum tube output at different kVs: With conventional tubes, sufficiently high mAs output at low kVs is only possible for pediatric examinations (blue arrows). New CT tube generations, however, can overcome this limitation. This enables a significant reduction in the kV, not only in protocols for children, but also for large adult scans (gray arrow).



This principle works on every CT scanner; however, for meaningful savings of contrast agent dose a significant decrease in the kV is required (see Fig. 4). In the past, it has not been possible to keep the dose constant at all kV levels, as the X-ray tubes were not powerful enough to produce sufficient tube current (mAs) at low kV levels. New X-ray tubes powering the new generation of scanners, like the SOMATOM Force, now have sufficient power to fulfill this condition (see Fig. 7).

An additional technical enhancement that enables the success of this principle are the availability of iterative reconstruction methods (such as ADMIRE and SAFIRE) and integrated circuit detectors

(Stellar detector) which help to reduce image noise at low kV scans and therefore allow for a diagnostic image quality even at low kV settings.

Low kV contrast CT scanning is feasible in clinical routine and, depending on user preferences, it can be used directly to reduce either radiation or iodine dose.

It is possible to use low kV imaging to save both radiation and iodine dose at the same time; however, the configuration of a suitable protocol is not easy and the reduction potential for both radiation and iodine is significantly less compared to the 2 methods described above.

The increase in iodine enhancement at lower kV can be utilized to reduce the contrast agent dose, while maintaining the image quality (CNR) at a given radiation dose.



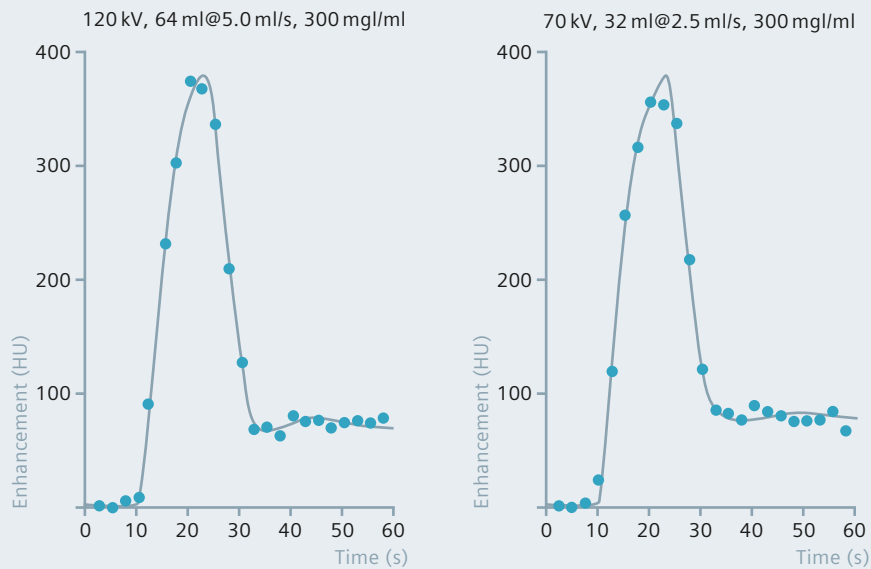


Fig. 8

Fig. 8: An animal study in pigs demonstrated that an identical temporal enhancement curve for the 120 kV reference protocol (left) and 70 kV protocol (right) can be obtained with constant injection duration and adapted IDR, while saving 50% in contrast agent. [Data courtesy of Lell et al]

## Saving contrast agent in clinical practice

If one changes from a reference scan protocol to a low kV protocol and one decides to reduce the contrast agent dose, the contrast injection protocol must be adapted to reduce the iodine load.

The easiest way to adapt the iodine load seems to be a reduction of the contrast volume without changing any other injection parameters.

However, a reduction in contrast volume leads to a shorter injection duration and, thus, to significant changes in the contrast enhancement over time: Peak enhancement occurs earlier, requiring adaptation of the scan delay, and scan timing becomes more critical because of a narrower enhancement curve.

To avoid these changes in scan timing, the preferred and most robust strategy to achieve contrast dose reduction is to keep the injection duration constant while reducing the iodine delivery rate (IDR).

Reduction of the IDR can be accomplished by lowering the iodine concentration and/or the volume and injection flow rate, which will lead to identical temporal enhancement curves for reference and low kV protocols.

As previously demonstrated in a pre-clinical animal study (Fig. 8), peak width, peak height, and peak time remain the same with a reduction of the IDR. More practical details, for instance about setting the  $CTDI_{vol}$  of reference protocols for lower kVs and adaptation of the bolus tracking parameters, can be found in the "How-to" guide, which provides step-by-step instructions for clinical application.

## List of references

### Scientific Publications:

- Siegel MJ, Schmidt B, Bradley D, Suess C, Hildebolt C. Radiation dose and image quality in pediatric CT: effect of technical factors and phantom size and shape. *Radiology* 2004; 233(2):515–522.
- Sigal-Cinqualbre AB, Hennequin R, Abada HT, Chen X, Paul JF. Low-kilovoltage multidetector row chest CT in adults: feasibility and effect on image quality and iodine dose. *Radiology* 2004; 231(1):169–174.
- Nakayama Y, Awai K, Funama Y et al. Abdominal CT with low tube voltage: preliminary observations about radiation dose, contrast enhancement, image quality, and noise. *Radiology* 2005; 237(3): 945–951.
- Fleischmann D, Kamaya A. Optimal vascular and parenchymal contrast enhancement: the current state of the art. *Radiol Clin North Am.* 2009 Jan; 47(1):13-26.
- Bae KT. Intravenous contrast medium administration and scan timing at CT: considerations and approaches. *Radiology* 2010; 256:32-61.
- Gnannt R, Winklehner A, Eberli D, Knuth A, Frauenfelder T, Alkadhi H. Automated tube potential selection for standard chest and abdominal CT in follow-up patients with testicular cancer: comparison with fixed tube potential. *Eur Radiol.* 2012 Sep;22(9):1937-45.
- Sodickson A, Weiss M. Effects of patient size on radiation dose reduction and image quality in low-kVp CT pulmonary angiography performed with reduced IV contrast dose. *Emerg Radiol.* 2012 Oct;19(5):437-45.
- Hough DM, Yu L, Shiung MM, Carter RE, Leng S, Fidler JL, Huprich JE, Yondal DY, McCollough CH, Fletcher JG. Individualization of Abdominopelvic CT Protocols With Lower Tube Voltage to Reduce IV Contrast Dose or Radiation Dose. *AJR* 2013; 201:147-153.
- Azzalini L, Abbara S, Ghoshhajra BB. Ultra-low contrast computed tomographic angiography (CTA) with 20-mL total dose for transcatheter aortic valve implantation (TAVI) planning. *J Comput Assist Tomogr.* 2014 Jan-Feb;38(1):105-9.
- Lell MM, Jost G, Korporeal JG et al. Optimizing contrast media injection protocols in state-of-the art CTA. *Invest Radiol.* 2015 (in press), DOI: 10.1097/RLI.000000000000119

Lu GM, Luo S, Meinel FG, McQuiston AD, Zhou CS, Kong X, Zhao YE, Zheng L, Schoepf UJ, Zhang LJ. High-pitch computed tomography pulmonary angiography with iterative reconstruction at 80 kVp and 20 mL contrast agent volume. *Eur Radiol.* 2014; 24(12): 3260-3268

Meinel FG, Canstein C, Schoepf UJ, Sedlmaier M, Schmidt B, Harris BS, Flohr TG, De Cecco CN. Image quality and radiation dose of low tube voltage 3<sup>rd</sup> generation dual-source coronary CT angiography in obese patients: a phantom study. *Eur Radiol* 2014 Jul;24(7):1643-50

Meyer M, Haubenreisser H, Schoepf UJ, Vliegenthart R, Leidecker C, Allmendinger T, Lehmann R, Sudarski S, Borggreffe M, Schoenberg SO, Henzler T. Closing in on the K Edge: Coronary CT Angiography at 100, 80, and 70 kV-Initial Comparison of a Second- versus a Third-Generation Dual-Source CT System. *Radiology* 2014; 273(2):373-382

Szucs-Farkas Z, Christe A, Megyeri B, Rohacek M, Vock P, Nagy EV, Heverhagen JT, Schindera ST. Diagnostic accuracy of computed tomography pulmonary angiography with reduced radiation and contrast material dose: a prospective randomized clinical trial. *Invest Radiol.* 2014 Apr;49(4):201-8.

**Websites:**

<http://www.nist.gov/pml/data/xraycoef>

**Siemens publications:**

Grant K, Schmidt B. Care kV – White Paper, Siemens Healthcare; A9115-11314-C1-4A00. 2011

Schmidt B, Raupach R, Flohr T. How to scan with CARE kV – User Guide, Siemens Healthcare; A91CT-23015-35C1-7600. 2011

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